

Report:

ISSUES RELATING TO ORGANIC WASTE DISPOSAL

PART 3 – UNDERSTANDING THE HOTROT SYSTEM

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Executive summary

This document explores the issues underlying organic waste composting, explains some of the fundamental facts of composting and illustrates the benefits of HotRot in-vessel composting systems. The report highlights how the HotRot composting system manipulates the important parameters of particle size, moisture, and temperature and residence time to produce consistent high quality compost from a large range of organic wastes.

This report is the third in a series of three which look at the science behind the operation of the HotRot system and composting in general. The first report in the series covers the issues of organic waste recycling (composting) and reuse and the second provides an overview of the HotRot composting system. Each report is complete in itself, but combined provide a detailed reference tool for those wishing to understand organic waste composting and the HotRot system.

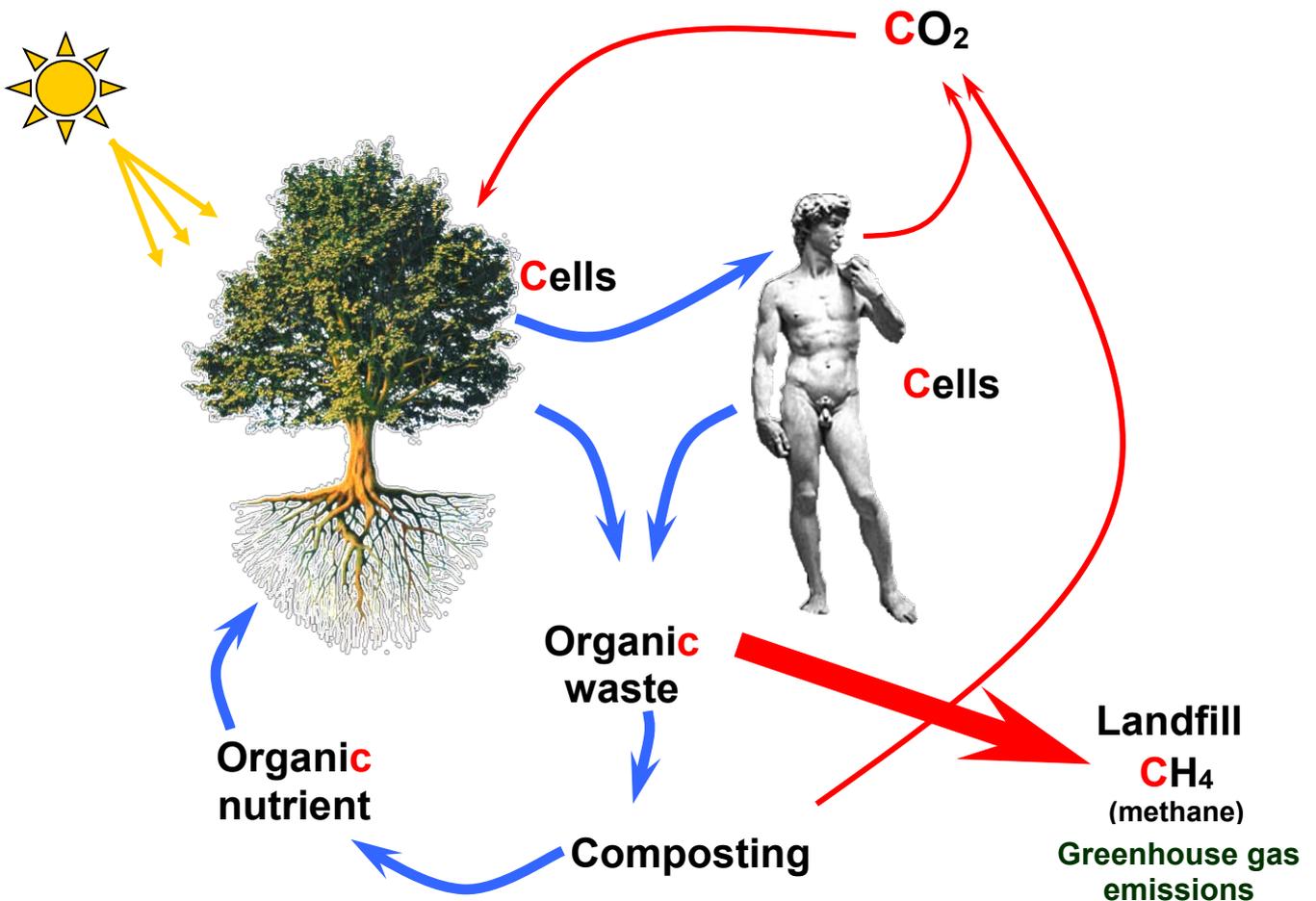
Understanding HotRot operation

The HotRot composting system differs markedly from other composting systems on the market and it is helpful to understand something of the philosophy and science underlying the system's operation in order to fully appreciate its benefits. It is also necessary to have some understanding of compost science as it relates to an in-vessel process, as distinct from the traditional windrow process. A great deal of composting knowledge is based on experience and observations of open-air windrow or batch systems; most of this knowledge is not directly applicable to the HotRot in-vessel composting system or needs to be re-evaluated in light of the HotRot system's unique features. Indeed a lot of this historical dogma lacks serious scientific critique or assessment and is not supported by more recent studies.

Why compost?

The importance of the carbon cycle

Most of us understand the carbon cycle in its basic form; plants produce oxygen from CO_2 and energy, and animals breathe in oxygen and produce CO_2 . However, this ignores a major portion of the cycle as illustrated below.



This simplistic understanding of the carbon cycle ignores the importance of cell recycling. Cell recycling, through processes such as natural decay and composting, is essential to release the carbon locked up in biological structures. Without this recycling we destroy a significant portion of the carbon cycle. Sending organic waste to landfill breaks the carbon cycle and produces the greenhouse gas methane, which contributes to global warming at a rate 21 times greater than that of CO₂.

Even the carbon cycle depicted above is a simplistic representation. Mini cycles, all of significant importance, occur within plants and animals and within the soil. Breaking or disturbing any of these secondary cycles can have long-term implications – nowhere is this more clearly demonstrated than in the clearing of tropical rainforests. Land cleared of tropical rainforest is initially fertile and able to support crop production but very quickly the carbon content is depleted (generally through leaching), the soil structure collapses and crops fail. This same effect is seen in temperate agricultural systems where carbon, in the form of compost or organic matter, is not recycled; but the process occurs much more slowly because of lower rainfall.

Composting has an important role to play in maintaining the carbon cycle and preserving agricultural production (see Part 1 of this series). Chemical fertilisers have significantly boosted agricultural production, but this has been at a cost of a slow deterioration in soil quality and health. Even maintenance of current yields into the future depends upon attention being given to conservation of soil organic matter. Compost application is a key component in addressing this issue.

Factors affecting the composting process

Temperature does not equal composting

Before we look at factors affecting composting it is first important that we understand what we really mean by composting. We are not talking about the textbook definition here but what defines composting from a biological and chemical point of view.

Most people believe that a pile of organic matter that has spontaneously heated to an elevated temperature in the centre of the pile is actively composting. This could not be further from the truth. A pile of organic matter will undergo low rate degradation, some of these degradative processes are exothermic (produce heat), this heat is trapped within the pile as the waste is relatively insulative; this is why we can see snow-covered composting windrows. The heat (or temperature) is not a good indicator of active composting but just an indicator that a small amount of heat being generated cannot escape. The reality is that unless heat is removed it will become inhibitory and will also result in localised drying, etc. A mass of material can only be considered to be actively composting when significant heat is being removed from the mass and the mass is able to maintain significant temperatures in the vicinity on 45-60°C (temperatures optimal for composting microbial growth).

A number of studies reveal that approximately 20 times more air is needed to remove the heat that can be generated in an **active** compost pile than is needed for aeration. One tonne of waste can contain 5-9,000MJ of energy, yet requires only 1,200MJ of this energy to maintain the pile at thermophilic temperatures, evaporate the 450-500kg of water produced by the process and heat the air required for aeration. In order to achieve a stable compost it is important to use as much of the available energy as possible; i.e. to completely use the fuel in the waste being composted¹, and remove excess energy released in the form of heat.

Biochemically therefore efficient composting should be defined as:

The aerobic degradation of waste to release the maximum amount of energy contained within that waste while maintaining temperatures at a level conducive to maximum microbial activity.

In other words, the composting process should be controlled to release as much energy as possible, as quickly as possible, while maintaining optimal conditions for microbial growth. In this regards, regular turning to ensure even distribution of heat and moisture with high-transfer of energy to air or other media should be the control goal.

Accepting this explanation also highlights that most international standards are fundamentally flawed as they impose a time at temperature regime on the process; some of which require a temperature that is clearly too high for active composting and therefore promotes inefficient processes with little or no turning and low rates of inefficient microbial activity.

¹ It should be noted that even efficient composting will only consume between about 35-60% of the available energy, depending on the waste.

Oxygen

Composting is clearly an aerobic process. Oxygen is required to support the microbial growth that drives the process and prevent anoxic (no oxygen) conditions that cause odours. As a biological process we must look at biology and chemistry to understand the system thoroughly.

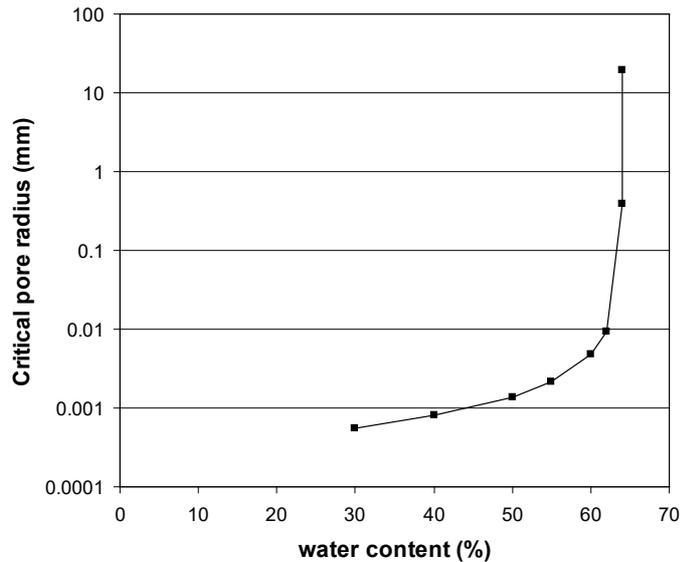
The oxygen component of air is an important factor in successful composting. Air is an efficient heat transfer medium and too much air can be detrimental; excessive heat is lost and compost material is excessively cooled and activity declines. However, as indicated above, 20 times more air is needed for heat transfer than is needed for aeration so - *in an actively composting pile oxygen levels should never be inhibitory.*

Composting involves particles of food (organic waste) surrounded by a film of moisture in which microorganisms live and act. Aerobic microbes need oxygen; this is obtained through the cell wall from the dissolved oxygen in the moisture surrounding the organisms; rather than directly from the air. Oxygen in the moisture is replenished from the surrounding air. The kinetics of diffusion is very efficient and even if the oxygen level in the air is very low it will still diffuse into the moisture layer, provided a concentration gradient is present. Because oxygen (in air) has a relatively poor solubility in water (10 mg/l at 15°C), which decreases markedly with increasing temperature, measuring oxygen levels in the free air space, as measured by probes, and maintaining the level of oxygen at high levels (such as >15% suggested by some advocates) does not necessarily promote optimal microbial growth. As long as there is some oxygen in the free air space aerobic microbial activity will proceed; supplying more oxygen will not speed up the process and may slow it down by evaporating the moisture and cooling the environment. Increasing airflow will not necessarily increase the concentration of oxygen in the moisture layer.

Another way to look at the oxygen gradient: 10mg/l of oxygen in water is equivalent to 0.000001%. Oxygen in air is normally 21% or 21 million times – if oxygen levels in the compost are 2% this is still a concentration gradient of 2,000,000 to 1.

The issues underlying air (oxygen) penetration is structure, moisture and heat release. Fast composting requires oxygen delivery to the microbial cells. This is optimal when there is an interlinked network of relatively small pores. Oxygen movement through water is around 10,000 times slower than oxygen movement through air. If pores are filled with water, the rate of oxygen transport will be too slow to sustain thermophilic composting. Richard (2000) explains the theoretical relationship between water content and the size of air filled pores (<http://compost.css.cornell.edu/oxygen/capillary.html>).

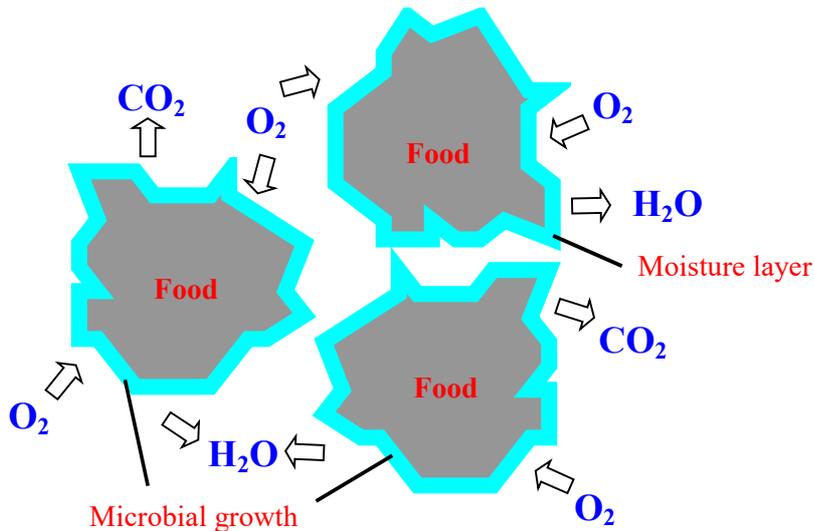
At any water content below saturation, capillary action within the waste will exert a negative pressure on free water in contact with the waste. This pressure can be related to a “critical pore radius” the critical pore radius is of great importance, as it describes the size of the waste pores that will be air filled – pores less than the critical radius will be water filled and those above will be air filled. This is shown in the graph below for a model waste. The shape of the curve is expected to be similar for all wastes, although the water levels at which saturation occur will vary considerably.



The importance of this concept lies in the shape of the curve, and the sudden change in free air space as saturation approaches. In the example above, at 62% water, pores with a radius above 0.01mm are air filled. At 64% water the waste is effectively saturated. This phenomenon illustrates the very sharp cut off between acceptable and unacceptable water levels that is not appreciated by many operators.

It is also important to appreciate that the process of composting produces moisture. If structure is marginal or air passage impeded low-rate composting will occur but this will also produce moisture which can quickly saturate pores or form leachate. If structure is poor acceptable moisture content is likely to be lower.

In a regularly well-mixed system, such as HotRot, oxygen recharge occurs during agitation but gaseous oxygen within the air space within the compost declines relatively quickly after shaft rotation ceases. This is exacerbated by small particle size and low free air space; a small volume of air is entrained in the composting mass. This is not problematic as periodic air injection is used by HotRot to maintain aerobic conditions. Shaft rotation is primarily concerned with heat distribution and release, moisture distribution and release and reducing any effects of waste compaction that might otherwise reduce effective pore-space or porosity.



Oxygen diffuses in to the moisture layer from the free air space between particles

This dynamic system results in composting at high efficiency, and operational parameters are readily tuned to achieve this. Nevertheless, intermediate 'air space' oxygen levels probably represent an optimal processing state. No free oxygen possibly represents high activity, which is probably retarded by periods of anoxic conditions. Areas with very high oxygen levels may indicate a lack of activity or over-aeration causing cooling and sub-optimal processing. Optimal oxygen levels may be in the range of 5-12% in the free air space.

Temperature

Composting is, by definition, a high temperature process occurring at over 40°C. This temperature is generated by the metabolism of the microorganisms growing on, and feeding off, the organic waste. The temperature is a function of the microbial activity it is not a driver (or cause) of the process. A large HotRot 3518 composting unit will generate in excess of 150kW of heat through microbial activity (respiration).

High temperature is important for a number of reasons, but target temperatures are complicated by somewhat conflicting constraints.

1. All reactions take place faster at higher temperatures; although for biochemical/biological reactions there is a definite upper limit and optimal range. Waste treatment and stabilisation will therefore generally be more efficient as temperatures rise. For reactions not involving cells this is a general rule, but for the cellular reactions important to composting the maximum degradation rate is achieved around a broad peak of 50°C. Higher temperatures lead to less cellular activity or death. While it is possible to achieve very high temperatures in composting systems (by avoiding heat release), these should be avoided except to the extent they serve to address performance standards, as outlined in point 3 below. Indeed, as stated, high temperatures are not an indicator of efficient processing simply an indicator of poor heat transfer. Even the most stable compost, with the right moisture content, will heat up when put in any sort of pile. This is simply an issue of thermodynamics and nothing to do with high microbial activity or degradation. Stable compost is not a fully mineralised product so further biological degradation can occur, however the rate at which this occurs is very slow - nevertheless compost is itself a very good insulator, so a process that releases even a small amount of heat will heat a large mass if that heat is retained as happens in a large pile or un-agitated mass.

2. Composting is a degradation process, with typically around 40-60% mass loss. This mass is largely lost as water vapour, which was originally present in the waste, and conversion of carbonaceous materials to carbon dioxide, water and other gases. A proportion of the heat produced during the composting process is lost through evaporation of moisture and indeed this is an important mechanism for controlling the moisture and heat balance of the system.
3. Control of harmful organisms in the waste is achieved through pasteurisation – a process that requires material to be held at elevated temperatures for minimum defined periods. In many cases local composting standards define minimum ‘time at temperature’ performance standards. It is of great importance, from a regulatory compliance point², that all of the composting material attains and maintains the proscribed minimum temperature.

Unfortunately, keeping composting waste at an even temperature is generally problematic. Composting is a biological process and therefore the amount of heat generated and the period over which a temperature can be sustained is dependent on the material being composted - the temperature is the result of composting - composting is not the result of temperature. With a variance in waste volumes and characteristics (moisture content, freshness, protein content, etc) the rates of "reaction" will also vary. This will result in the temperature peak inside the process moving both spatially and in magnitude. Simply because a Standard proscribes a waste must achieve a certain temperature for a certain period does not mean it will or indeed it can.

In a pile, the environment will cool material on the edges, and the centre may overheat. Accepted risk assessment methods show that the hazard associated with harmful organisms from compost is mainly due to the potential for waste to escape treatment through these ‘edge effects’. The way that this can be overcome is through agitation. By mixing the compost, material from the edges is transported to hot areas. Standards typically require such mixing to occur 5-10 times during the thermophilic composting process, but in HotRot mixing occurs more than 4-500 times in this period. As a result, the risk of pathogens escaping treatment is extremely low and microbiological testing confirms this.

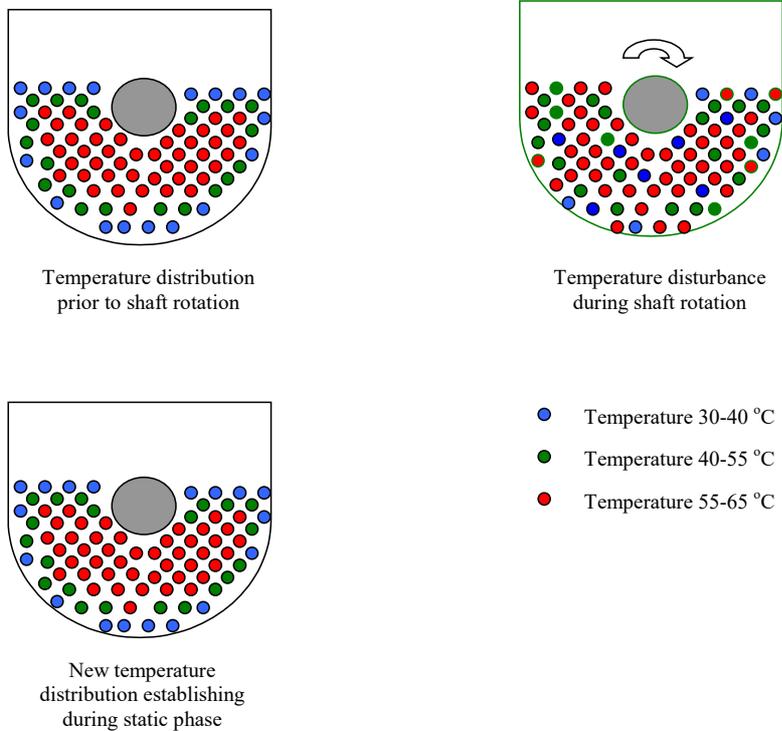
Additionally, pathogens simply become another “food” particle for the microbes responsible for composting. Pathogens are not adapted to elevated temperatures, and indeed some do not grow well in oxygen rich environments, as such the pathogens themselves become food for the thermophilic microbes that are active in the composting material. Thus, pasteurisation can be effected over any temperature range where composting microbes predominate and thrive. Thus pathogen reduction, in a well mixed, active system, such as HotRot, can occur at temperatures as low as 43°C; see Table below.

The Table highlights that compost produced by the HotRot process can be expected to have acceptable pathogen levels even when temperatures in the vessel are below those commonly regarded as essential for pathogen reduction. The results highlight the advantages of thorough mixing and maintenance of a highly active composting environment.

² Even though the effective temperature required for pasteurisation may be significantly lower than that stated by the standards.

Summary of microbial testing result from HotRot composting vessel processing sewage grit and screenings				
Maximum in-vessel temperature	Days material exposed to >40°C	Total coliforms (MPN/g)	Faecal coliforms (MPN/g)	Salmonella
63.5	14	23	<3	Not detected
63.2	14	4	<3	Not detected
63.2	14	43	15	Not detected
62.8	14	23	<3	Not detected
60.4	13	<3	<3	Not detected
56.6	12	4	4	Not detected
48.6	12	75	<3	Not detected
47.8	12	240	240	Not detected
45.9	12	23	23	Not detected
46.4	12	43	15	Not detected
46.6	10	23	23	Not detected

The HotRot system has been devised to take advantage of the natural insulative properties of the compost mass and the need to thoroughly mix the material so that edge effects are frequently destroyed. This occurs as a result of shaft rotation. During a static period edge effects can be measured but regular shaft rotation (generally every 30-60 minutes) mixes the material, destroying these transient effects. The result is that all the material is evenly composted and no material passes through the unit that has not been exposed to extended periods at high temperature (active composting); the following figure serves to illustrate this point.



Transient “edge effects” are destroyed by shaft rotation within the HotRot unit

Particle size

The above discussion obviously raises the issue of free air space and particle size. This is another traditional area of conflict within the composting process. Smaller particles will compost faster but smaller particles pack closer together reducing the free air space, potentially reducing airflow and impeding aeration as discussed. This is further exacerbated in piles and static-stack systems (or indeed vertical towers) where smaller particles are prone to compaction. Most systems overcome this issue by using quantities of coarsely shredded bulking agents such as green waste (yard waste or wood). The HotRot system overcomes the problem by rotating the shaft and stirring the material relatively frequently. Every shaft rotation lifts material from the bottom of the mass to the top and vice-versa; any compaction that has occurred during the static period is loosened up. As material from the top is taken down to the bottom so is air. This provides some of the oxygen needed for the composting process to proceed until the next rotation. The process can be tuned to behave optimally via the control system. The net result is that the HotRot process can handle material of a smaller average particle size with resultant improvements in compost quality. Fine material at the start of the process means finer material at the end with fewer overs at screening and maximum use of the HotRot vessel's volume.

Another important benefit of the HotRot system's relative insensitivity to inherent porosity is that the need for bulking agents is significantly reduced. Dry bulking agents are required primarily for moisture control and secondarily to maintain porosity. Trials have shown that to compost sewage treatment plant grit and screenings in a static stack, bulking with green waste at around 1:1 by mass is necessary. In the HotRot system these materials can often be processed without the addition of any bulking agents, provided the initial moisture level of the material is less than 60% by mass.

The HotRot process also manipulates particle size and therefore bulk density through the action of the tines. Tine movement through the material being composted generates significant shear forces, these forces, combined with microbial degradation, leads to particle size erosion. This erosion of particles can result in a significant increase in material bulk density within the first few meters of the HotRot vessel; an initial bulk density increase of greater than 20% from 700kg/m³ to 850kg/m³ has been measured.

Moisture

As stated, air is required as part of the composting process for removal of moisture. All organic matter is primarily composed of carbon, hydrogen and oxygen atoms, with other atoms within the molecules such as nitrogen, potassium, etc, adding functionality. During degradation some of the C, H and O is released in the form of CO₂ and H₂O, the water thus formed must be removed from the system otherwise the process would become too wet, oxygen diffusion would be impeded and microbial activity (and resultant temperatures) reduced; the microbial heat would be consumed in raising the temperature of the greater proportion of water resulting in lower microbial growth rates and a downward spiral leading to system failure. Additionally, high moisture levels results in the "flooding" of pores, which in turn inhibits oxygen diffusion as discussed above. Obviously in the extreme, excessive moisture will fill the void volumes completely, eliminating all free air space.

Moisture loss is responsible for much of the mass reduction observed during composting. Traditional composting systems rely on moving excess quantities of air through the composting mass so as to draw out the water as a vapour. As already discussed this is generally inefficient (leachate is still produced) and excessive aeration increases edge

effects and reduces microbial efficiency through excessive localised cooling and drying. The HotRot process deals with the issue differently.

Moisture is primarily lost from the compost mass when it is agitated or turned; this effect is normally observed when digging into a pile of compost. In the HotRot system air is drawn through the unit and over the top of the material being composted and is also injected into the bottom of the vessel to move up through the material and into the head-space. During static periods the air drawn through the system is reduced to a level that removes any vapour and maintains the system under slight negative air pressure, thus controlling fugitive odour emissions but also preventing over-drying. During shaft rotation the exhaust fan accelerates and the volume of air drawn through the unit, and the material, is increased dramatically so that all liberated moisture is removed. This approach offers a number of advantages over alternative systems.

- The amount of air drawn through the HotRot system is optimised for moisture removal when it is liberated; this reduces the volume of air requiring treatment and significantly reduces the power consumption of the air exhaust fan.
- By effectively distilling the excess water, nutrients and particulates remain in the composting material where they belong; they are not leached from the process. Excess moisture and carbon dioxide is also released before it reacts and has a chance to lower the pH and inhibit the microbial process.
- The moisture moves up into the air stream by convection and a relatively small volume via low pressure supplementary air injection rather than all as a result of the passage of large quantities of air through the compost mix. This reduces edge effects and excessive cooling.
- Moisture loss from the system can be controlled by fan speed based on differential air temperature and/or humidity (the difference between the outside ambient air and the temperature or humidity of the air exiting the HotRot unit).
- The ambient air entering the unit (either via injection or passively) can be heated to further optimise moisture removal and minimise the effects of cold climates. Heating can be provided directly or via a heat exchanger/heat pump operating off the exhaust air.
- The net effect is that moisture is lost as vapour and the system does not produce any leachate.

As with any composting system the waste entering the HotRot unit should have moisture content in the range of 40-60% by mass. However, the HotRot system also offers the ability to control moisture loss through the process outlined above. Because the HotRot units are enclosed there is no environmental drying from wind or sun. The moisture loss from the system can be controlled by air flow and air temperature (both incoming and exhaust air temperature). The volume of water that can be carried in a fixed volume of air doubles for every 10°C rise in temperature. As the air moves through the HotRot unit its temperature will increase by 15-25°C, if the incoming air is at 15°C then significantly more moisture will be removed than if the incoming air is at 5°C; as a result there can be a provision for heating the incoming air prior to it entering the HotRot composting vessel. The rate at which air is drawn through the unit (or injected into the unit) also impacts on how much the temperature is increased during its passage through the system, simply drawing greater quantities of air through the unit may not increase moisture removal if the temperature of the air is too low.

Carbon and nitrogen ratio

The carbon:nitrogen (C:N) ratio is often raised as an important parameter to consider when composting wastes. In reality the C:N ratio is simply a crude measure of the expected rate

of composting or the oxygen demand of the waste. Materials with a lower C:N ratio will compost faster and therefore have a greater oxygen demand.

This is a significant issue for windrow composting and other processes that are less efficient at aeration or do not have flexibility in the amount of aeration they can provide. In these cases the high oxygen demand will result in anoxic conditions and odours. In addition, wastes that contain higher proportions of nitrogen will generate higher concentrations of ammonia (NH₄). Ammonia generation results in odours and is the primary reason why C:N ratios have been prescribed in the past; it is difficult to get sufficient aeration into a windrow or static system in order to prevent ammonia build-up and odour release during handling. The HotRot system is tolerant of low C:N ratios (high potential ammonia levels) and indeed these wastes are preferred as they will compost faster, resulting in greater mass and volume reductions further maximising the effective use of the HotRot unit's fixed volume. The HotRot system overcomes the inherent issues that wastes with a low C:N ratio pose by processing all air through a biofilter and being able to increase agitation/aeration to compensate for the higher oxygen demand.

HotRot is not designed, and indeed is not efficient, for processing waste with a high C:N ratio or slow rate of degradation such as woody material. Green waste (woody material, not lawn clippings) on its own has little readily available energy (a low oxygen demand), as such it does not require much aeration as the rate of oxygen utilisation is low and it will not generate much heat. In addition, the throughput of the HotRot unit is based on the rate of degradation of the material being composted and therefore the mass and volume reduction that occurs during the time the material is in the unit. Green waste degrades slowly, mass and volume reduction is low; either throughput volumes need to be reduced or a very short residence time will result. The goal should be always to have the minimum amount of woody material in a mix to satisfy the needs for porosity and moisture (material that is the right moisture but lacks any structure will still not compost efficiently).

Mixing

The importance of mixing from the point of view of maintaining oxygen levels and eliminating edge effects has already been discussed but mixing is also important in that it ensures all material is evenly composted and exposed to the active composting process (or elevated temperatures). This is of particular importance when considering pathogen removal, product safety and product "maturity" as defined by such tests as the Dewar flask.

If we look at a windrow that is 4m wide at the base, 2.5m high and 10m long it will contain 50m³ of material. If we then assume that the material around the edges to a depth of 5cm is only exposed to low or ambient temperatures then 6.4% of the mass will be inadequately treated. Pathogen levels in organic wastes, especially sewage residuals, can be as high as 1.0 x 10¹² MPN/g³. International standards for unrestricted use compost generally require pathogen levels to be less than 100-1000 MPN/g. In order to meet these levels a windrow pile will need to be turned in theory 8-9 times (see below) and the material being composted maintained at temperatures sufficient for pasteurisation for this period. Many windrow systems will achieve this. However, many static stack or non-agitated systems will not.

If we assume waste to contain 1.0 x 10¹² MPN/g initially and 6.4% of our windrow in untreated then:

- After 1 turning and subsequent exposure of the material to elevated temperatures the pathogen content will be reduced to 6.4 x 10¹⁰ MPN/g

³ MPN = most probable number.

- After 2 turnings – 4.1×10^9 MPN/g
- After 3 turnings – 2.6×10^8 MPN/g
- After 4 turnings – 1.7×10^7 MPN/g
- After 5 turnings – 1.1×10^6 MPN/g
- After 6 turnings – 68,700 MPN/g
- After 7 turnings – 4,400 MPN/g
- After 8 turnings – 281 MPN/g
- After 9 turnings – 18 MPN/g

It can be said that HotRot goes well beyond the call of duty with respect to pathogen elimination. Under normal conditions the HotRot shaft will be rotated for at least 1.5 revolutions every 30-45 minutes, so even if we assume thorough mixing once every hour (which is conservative) then the material in the unit is mixed 24 times per day. Over a normal process of 10-12 days this would mean the material is mixed between 240 and 290 times.

Mixing or shaft rotation in the HotRot unit also has another important function. The action of the tines on the shaft generate significant shear forces, the large commercial HotRot 3518 unit is able to generate 12 tonnes of force on the ends of its tines. This shear force effectively sweeps degraded matter off the surface of a waste particle accelerating access for microbes to the underlying non-degraded organic material. In addition, the shear forces physically erode and break particles – the composting process is therefore facilitated by a combination of biological and physical processes.

Mixing within the HotRot system is consciously inefficient, that is, mixing is relatively efficient in the vertical plane but significantly less efficient in the horizontal plane. This is important for two reasons.

1. We do not want to mix composted material near the back of the unit with un-composted material from the front or have a potential for “short circuiting”, and
2. We do not want to actively mix biological populations that may be spatially distributed along the length of the unit, as some processes may be inhibitory to others.

Residence time

It is important to note that throughput is not directly a function of shaft rotation (due to inefficient longitudinal mixing) but is a function of the physical and chemical attributes of the material fed to the composting vessel and the rate at which the material is fed. This is completely different to any batch or static system. In a batch system the throughput is purely a function of the volume of the composting unit. The unit is filled to its working volume and then the material is left to compost, the resulting volume of compost is then removed from the unit at the end of the process. In contrast, the time material takes to pass through a HotRot unit is a function of mass and bulk density of the material added on a daily basis and the rate at which the material degrades and the resultant loss of mass and volume through the process. Bulk density, is initially increased by the action of the tines, partially through physical erosion (making particles smaller so they pack more closely together) and partly through mechanical compaction. Mass loss is related to speed of degradation – woody materials will degrade much slower than food type material, thus the residence time for a given volume of woody waste (garden waste) will be less than the same initial volume of food waste.

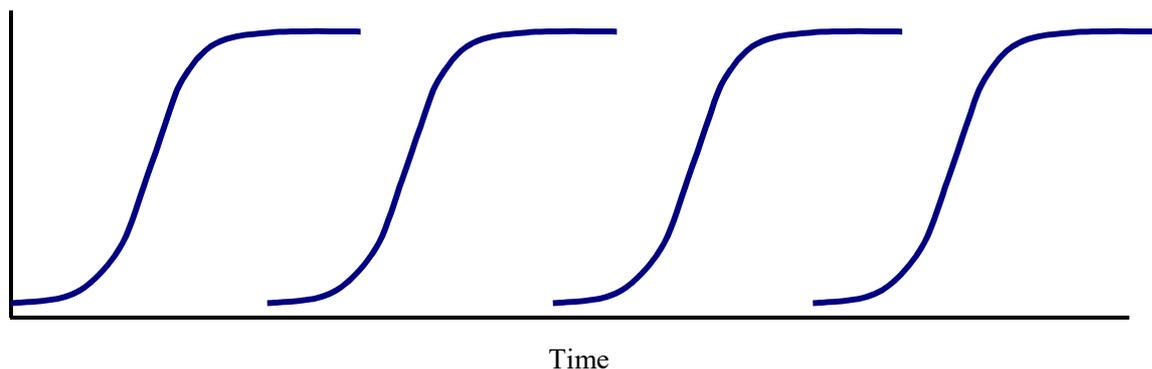
The rotation of the HotRot shaft can have a slight influence on residence time but discharge is largely influenced by the volume of waste added on a daily basis. If less waste is added

one day, then less material will be discharged assuming the same shaft rotation periods. It is not possible to fully empty a HotRot unit via shaft rotation.

Microbial Processes

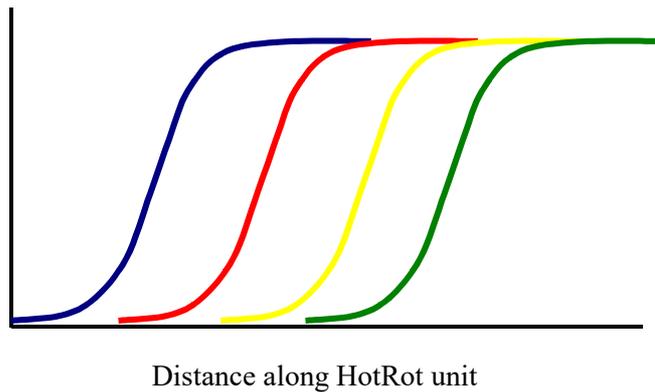
Composting occurs through a series of microbial processes. These processes involve different microbial populations, which utilise different food sources (compounds or types of wastes such as protein, fats or carbohydrates, etc) and different environmental niches (i.e. pH). Microbial growth is characterised by colonisation, growth, population maintenance and then decline. In some cases it is necessary for certain microbes to complete their metabolic processes before environmental conditions can change and other microbes colonise and take up the composting process.

Any batch composting system will be characterised by a number of microbial stages occurring successively over time. This inevitably results in extended composting periods, as a new population cannot establish itself effectively until the current population has exhausted its resources and the environment can change. Indeed in some cases one microbial population generates the food for the next population or may indeed produce inhibitory enzymes that restrict the development of another population until the numbers of the first population decline below a critical level.



Longer composting times caused by successive microbial populations developing over time

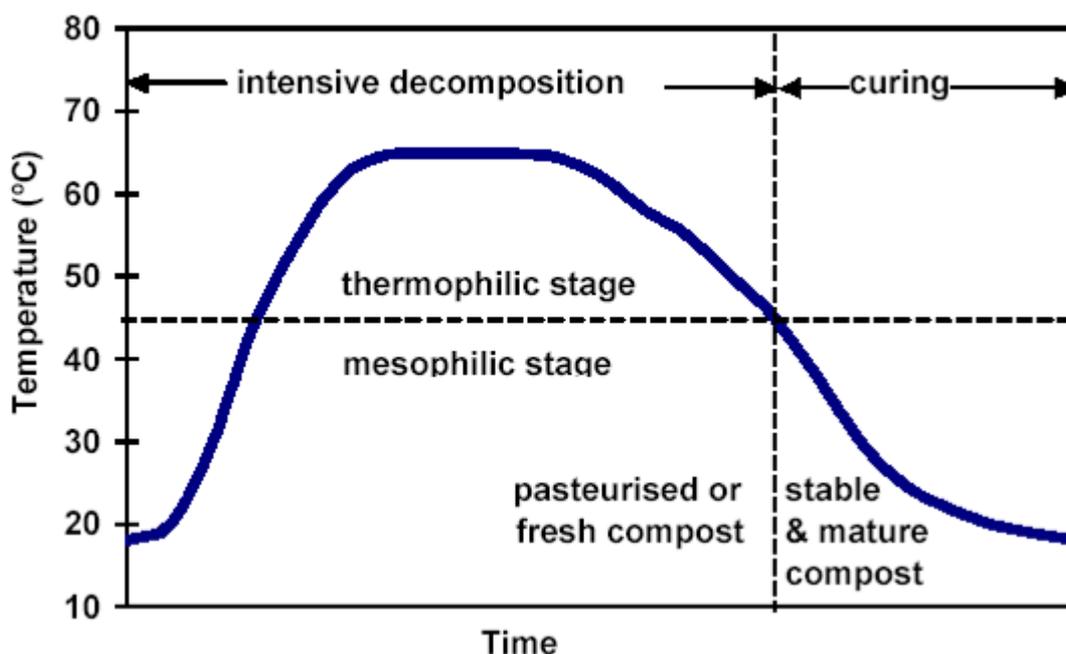
The HotRot composting system is a “continuous flow through system”; that is, the material to be composted is moved through successive populations of microorganisms by the rotation of the shaft and displacement caused by the addition of fresh material to the front of the unit. The different microbial populations are separated in space - not in time; effectively there may be a different population of microorganisms in different sections of the unit. The net result is that the same microbial processes depicted above can occur in a much shorter time period (as illustrated below).



Shorter composting times resulting from successive microbial populations being separated by space, not time.

As the material being composted moves through the HotRot system it is inoculated by the microbial population in the proceeding segment, this significantly reduces the period of colonisation and growth because colonisation is being driven from a large base population rather than from a zero or very low base. The volume of “fresh” material is also small in comparison to the mass already in the unit.

As the various microbial processes are completed the nature and stability of the material being composted changes. Initially microbial activity is able to exploit the readily available foods, these are the sugars, etc (the same ones that give us our initial boost of energy after a meal). These readily available nutrients result in rapid microbial growth and this phase of the composting process is characterised by the high thermophilic temperatures (ranging from 50-65°C). It is worth noting that the upper temperature is just as important as the lower temperature when considering composting efficiency. Microbial efficiency, at least in terms of the composting process, is significantly retarded above 60-65°C. Above these temperatures a different microbial population establishes which is unable to complete some of the biochemical processes required for effective stabilisation of the organic waste.



Temperature profile of the composting process

Once the readily available nutrients have been exhausted, different microbes then become dominant that can metabolise more complex molecules; these organisms typically operate in the meso-thermophilic temperature range of 40-50°C. The remainder of the composting process is characterised by a succession of microbial populations each able to metabolise successively more complex molecules until eventually the process is dominated by fungi which breakdown complex molecules like lignin.

Because the composting process represents a continuum it is possible to “split” the process in time and space. That is, it is possible to achieve thermophilic composting and pathogen elimination in an in-vessel system and then move to a windrow facility to continue the process, all-be-it at a slower rate. However, one must be careful.

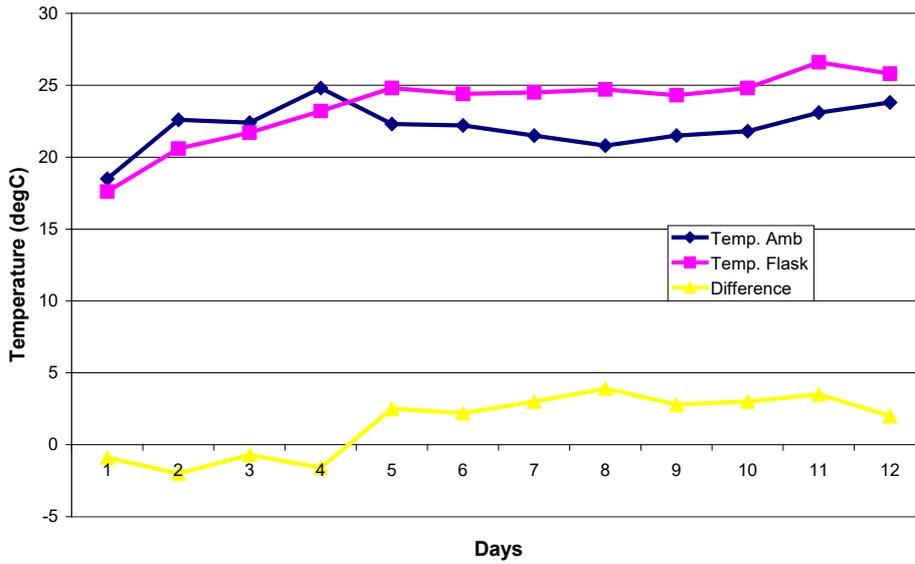
In addition to the composting process being characterised by successive microbial populations it is also characterised by a successive reduction in the level of “volatile solids”. Volatile solids is essentially a measure of the amount of material that can be organically converted and can be expressed on a mass per mass basis or on a % mass of the initial sample. Volatile solids are also an indirect indicator of odour potential. A sample with high volatile solids content will, generally, contain a high proportion of short-chain volatile organic molecules; these short-chain molecules are often the ones we associate with odour, for instance they give wine and vinegar etc, their aromas.

As the composting process proceeds, then the volatile solids content decreases, as does the potential for odours. This fact has been utilised by many international composting standards in specifying what is known as vector attraction reduction or VAR. It is recognised that vectors; rats, mice, birds, flies and other animals, are attracted to rotting organic matter by its odour, as the material decays and stabilises then the vectors (of disease transmission) are not attracted to the material. Demonstration of VAR is another important parameter with respect to residence time. Most standards specify that to demonstrate VAR the composting process must have achieved temperatures greater than 40°C and an average of 45°C for 14 consecutive days. An alternative approach is to measure the reduction of volatile solids direct, whereby VAR is assumed to have been achieved if the volatile solids content of the sample is at least 38% less than the original material.

As with the temperature standards for pathogens, those for VAR are simply a surrogate. Just because compost has not been above 45°C for 14 days doesn't mean it can't meet the VAR standard if volatile solids are measured direct. If a process is actively composting, as is the case in a HotRot, rather than just idling, as is the case in most composting system, then VAR can be achieved in a much shorter time period. Testing of compost from a HotRot system clearly supports this.

As an alternative to specifying a VAR, some standards set a maturity standard based on the potential for the material to re-heat when held in an insulated flask – the Dewar flask test. As previously stated, any material, no matter how well composted, will generate a small amount of heat as the organic matter is not fully mineralised and most reactions (especially biological ones) are exothermic (generate heat). The Dewar flask test overcomes this issue to some extent by using a relatively small test volume (2 litres); as such only material with significant microbial activity will result in a measurable temperature rise.

Dewar Flask Results - Selwyn October 2006



The ability of any composting process to produce a stable product offers a significant commercial advantage. Space needed for, and therefore the cost of, product storage is significantly reduced; as is the potential for generating odours. Again, the combined technical advantages of the HotRot process lead to a more stable product. Indeed, material that meets the new 2006 Canadian Council of Ministers of the Environment (CCME) guidelines for compost maturity can be produced on discharge from the HotRot vessel, see below. The CCME guidelines set a maximum temperature rise in the product, with respect to ambient, of less than 8°C.

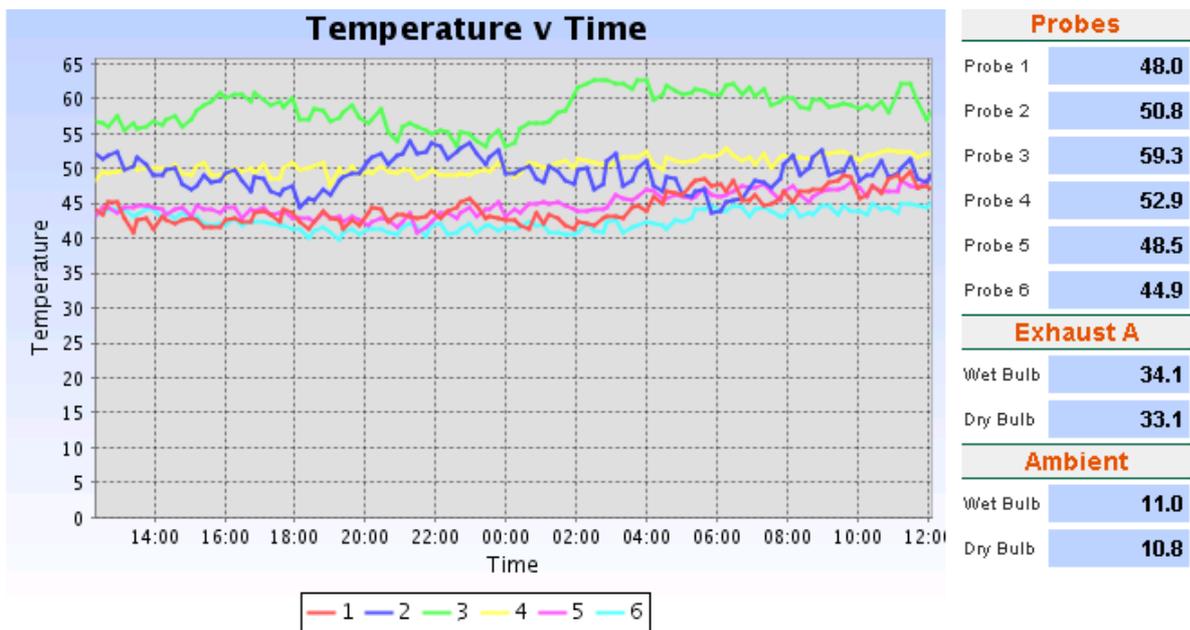
Storage and nitrification

There is one microbial process that cannot normally occur within the HotRot unit and indeed generally only occurs after extended storage. The conversion of residual ammonia to plant available nitrate-nitrogen requires nitrifying bacteria, nitrifying bacteria can only survive at temperatures below about 30°C. The conversion of ammonia to nitrate-nitrogen is important for some uses of the compost. If the compost is going to be spread on to agricultural soils then nitrification will occur as a result of the nitrifying bacteria in the soil and storage or curing is not required. However, if the material is to be bagged or used in conjunction with seedlings then the compost must be stored or “cured” to allow nitrifying bacteria to colonise the material and convert the ammonia. Additionally, if bagging the product, the moisture content of the product must be less than 20-25% by mass in order to prevent sweating and arrest any residual microbial activity. To facilitate this, curing piles should be kept as small as practical and turned regularly. If compost is stored in large piles the centre of the pile will not cool (even with low rates of degradation, as discussed previously) and will stay moist, therefore nitrification can be inhibited and ammonia can be released when the material is disturbed.

Demonstration of compliance

While providing the optimal conditions for composting is all well and good, today's standards demand that these conditions be monitored and auditable. The HotRot system can integrate a variety of sophisticated monitoring and recording systems depending on the requirements of the individual installation.

In its basic form the HotRot control system is able to monitor processing temperatures along the length of the unit. Temperature probes measure the temperature of the compost close to the side of the hull and data is recorded. This data can then be combined with residence time to generate a time/temperature profile for the product discharged from the system.



In-vessel temperatures recorded by six temperature probes spaced along the length of the HotRot unit.

The residence time within the HotRot unit is generally determined periodically using a chemical tracer or “ball” method. A compound such as calcium carbonate is added to the waste entering the unit; samples of compost are then taken at periods either side of the expected residence time. These samples are analysed for calcium. The concentration of calcium in the samples collected over time indicates the mean residence time and the variance around this mean. Alternatively, vinyl practice golf balls or RFID tags can be used as a physical tracer. Solid vinyl practice golf balls have a density of about 0.7-0.8 g/cm³, which is similar to compost. At least one dozen balls should be added with the material to be composted. The ball method is cheaper and simpler than the chemical tracer but solid vinyl balls must be used.

In general, residence time auditing is only required every 6-12 months or when there is a significant change in the waste being processed and the subsequent processing parameters such as shaft rotation times.

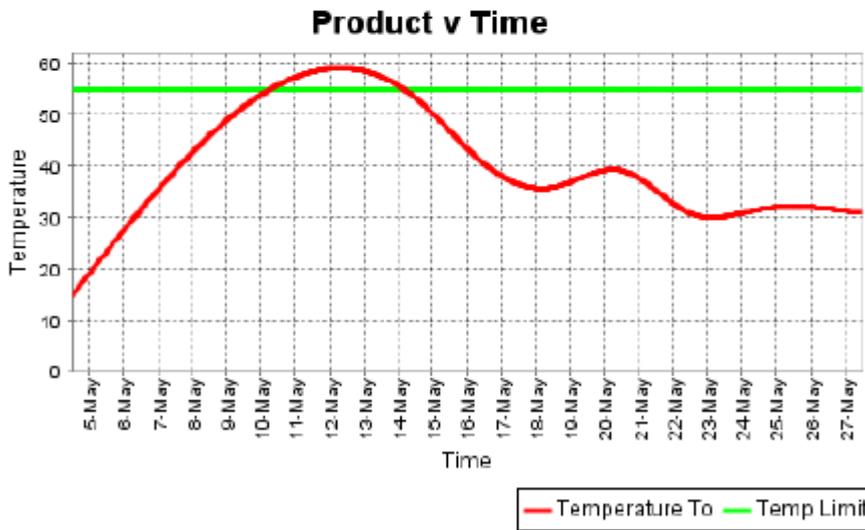
Processing Performance Report HotRot Composting Facility

Name of Facility: Rolleston Resource Recovery Owner: Selwyn District Council

Address:

Description of Waste: Food and green-waste from kerbside
 Performance Standard: AS4454, 55C / 3 days plus VAR
 Date of Discharge: 25-May-2006 12:00 NZST through 27-May-2006 11:59 NZST

Time Temperature Exposure Chart - Line 1



Pass

Remedial Action:

An example of a performance report generated from temperature measurements inside the unit combined with an assessment of residence time.

In addition to compost temperature and residence time auditing, the HotRot control system can be configured to record the following:

- Ambient and exhaust air temperatures – these can be used to regulate the exhaust fan and air heating system.
- Exhaust air CO₂ concentrations – a useful measure of overall respiration or rate of composting.
- Condensate or exhaust air moisture pH – another useful measure of composting performance.
- Motor currents and running times can be monitored to control feed rates and also schedule maintenance.
- The moisture content of the feed material can also be measured using microwave technology. This technology is expensive and therefore only appropriate for large installations. Off-line measurement using a laboratory balance is more cost effective in most cases.

- The mass of feed material can be measured using weigh-cells. This can be used for auditing purposes and also to control feed rates more evenly, especially between multiple units.

The control system also keeps a record of processing parameters such as forward, reverse and static times, exhaust fan settings and feed times. All this information can be summarised in processing reports, which can be downloaded to a remote computer.

Putting it all together

While we have talked about oxygen, temperature, moisture, particle size, mixing and residence time all in separate sections it is clear that all these parameters are interrelated and the most successful composting system will optimise these complex relationships. The preceding sections have highlighted how the HotRot system has been designed to provide the optimal conditions for composting, and the elimination of pathogens and vector attractiveness. To efficiently commission a HotRot composting plant it is important to understand the relationship between the physico-chemical make up of the waste to be composted so as to tune the operating parameters of the HotRot unit.

The HotRot unit itself is only a part of the HotRot system. Waste inspection and sorting equipment, shredders, automatic feed hoppers and product screens can all form part of an integrated system that ensures efficient and simple composting. HotRot works with its customers to identify their needs and provide an integrated solution from waste reception, through pre-processing, composting and final product handling and use. The company has installed its proprietary HotRot in-vessel composting systems in more than 11 countries since its inception in 2003.